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Underwater Dispersion of Air-laid Ground Mines
Operation MUD - 13 December 1951 to 12 February 1952

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Underwater Dispersion of Air-laid Ground Mines
Operation MUD - 13 December 1951 - 12 February 1952

by
M. C. Mertz and R. K. Smither

Summary

1. This is a report of an investigation of the underwater dispersion of air-laid ground mines, based on data obtained by optical sights during Operation MUD, Yorktown, Virginia, between 13 December 1951 and 12 February 1952. The results are first stated in the form of rectangular coordinates of the splash point with the origin taken at a fixed point on shore. Underwater range and underwater course azimuth (defined on pp. 2, 3) are analyzed to determine angular and radial distribution of the mines recovered.

2. The number of mines recovered within a given radius amounted to about 71% for a 25-meter radius, 82% in a 50-meter radius. Those for which the distance was more than 50 meters correlate strongly with skips, long "slides" on the surface, or secondary splashes on radar or films. No depth correlation was possible for reasons discussed on page 7.

3. A marked forward asymmetry was found, twice as many of the mines lying forward of the splash as behind it. Left-right asymmetry was not noticeable.

Data and Reduction to X, Y Coordinates

4. The original splash data were obtained by three theodolite observations of each splash, and recorded as angles with reference

to other observation points. Geographic coordinates of the observation points are available elsewhere[1], and these points are plotted and labeled on the chart, Figure 1. Also shown on this chart are the target positions, labeled with the dates. Where two different target positions were used on the same date, they are labeled A and B.

5. Coordinates of the vertices of the error triangle resulting from the intersections of the three sighting lines were calculated trigonometrically and plotted, and a geometric method of finding the most probable splash point from the error triangle was devised and used[2,3]. It is to be noted that this treatment of the data gives a check on the computations, as the sides of the error triangle, once the vertices have been plotted, must be parallel to the original lines of sight. Further, the size of this triangle gives an immediate idea of the dependability of the observations used. The method of analysis involved taking the three observations to be of equal weight. We have assumed, in other words, that at the ranges at which these sights were taken the most important source of error would be difficulty in ascertaining the center of the splash, hence the error (the distance from the true entry point to the sight line) would be substantially independent of the distance of the splash from the sighting point.

6. The mean probable error[4] in the position of the splash point is 6.1 meters. The median probable error is 2.2 meters, the difference being due to quite large probable errors in a small number of cases.

7. Recovery points in general involve only two sights, and for this reason no estimate as to their accuracy is feasible. Moreover, radar data are not available to check dubious recoveries.

8. All splash points are stated in cartesian coordinates with the origin at the observation point on Pier Two. For convenience, the positive X axis was taken true east, the positive Y axis, true north. Units are meters.

Further Reduction of Data

9. Two parameters, defined in an earlier study of the same nature as this one[5], are of particular concern:

(a) The underwater range, defined as the horizontal distance between the mine's entry point into the water and its resting point on the bottom.

(b) The underwater course azimuth, defined as the horizontal angle between the aircraft path and the radius vector drawn from the water-entry point to the resting point.

10. Table I includes the rectangular coordinates of the splash point, underwater range and course azimuth, probable error of the splash point determination, drop area, type of mine, altitude, and any special features of the drop, recovery, or computations.

Analysis

11. Figure 2 is a plot of underwater range and course azimuth for the 48 usable drops. Results which are obviously absurd (appar-

ent underwater range greater than 400 yards, not in a forward direction) appear in four cases, and are thought to be due to major errors in the observations of the recovery, as the splash points check well with radar observations and the error triangles are small. These four cases have been excluded from consideration. In addition, eight drops for which no recovery was made, or for which no sights were taken on the recovery, have been excluded. All other drops are considered. It must be pointed out that presumably the dispersion distance of drops for which no recovery was made would be greater than average, else the recovery would have been successful. However, we have no way of establishing a correction in these cases.

12. An attempt was made to discover the explanation for reasonable but exceptional values of underwater range (greater than 50 meters), and to this end motion pictures, photographs, and radar results have been studied. It now appears that in all such drops for which motion picture or radar data are available, the behavior of the mine involved either a long "slide", as shown on the radar, or a definite "skip" or secondary splash or some other nature, detectable on radar, films, or both.

13. Figures 3a, 3b, 4a, and 4b are separate plots of the underwater range and course azimuth for certain drops having a significant parameter in common. Too few data are present to make individual histograms practical.

Figure 3a includes all drops nominally made in drop areas I and Dog, average depth 41.2 feet. Target positions for these drops are shown as solid circles on the chart, Figure 1.

Figure 3b includes all other drops, nominally made in drop area II, average depth 55.8 feet. Targets for these drops appear on the chart as open circles.

Figure 4a presents all drops made with parachutes.

Figure 4b includes all drops made from high altitudes. Dive angles and altitudes are indicated by the symbols used.

14. Radial distribution: Figure 5a indicates the number of mines, and the percent of all mines considered, having an underwater range less than a given value, i.e., the total number of mines to be found in a circle of given radius centered at the splash point. There are several apparent "gaps" in the curve. In all probability, these gaps mean merely that no mines happened to be recovered at this particular distance from the splash point. Presumably, such gaps would be smoothed out if enough data were available. It will be noted that about 71% of the recovery points fall within a circle of radius 25 meters from the splash point, and about 82% within a radius of 50 meters.

Figure 5b shows the number of mines to be found in a ring five meters wide, centered at the splash, plotted against the inner radius of the ring at five meter intervals. The total number of mines in the first ring is somewhat smaller than the number in the next ring, due to the greater area of the second ring.

Figure 5c presents the same data in a different form. Here we have the number of mines to be found per unit area (500 square meters) in the same intervals as Figure 5b. As has been pointed out previously[5], this form of the data should afford a more useful criterion in evaluating underwater mine location.

15. Angular distribution: Figure 6 shows the number of mines in a 30° sector whose center line makes a given angle with the course of the aircraft, plotted at 10° intervals. No distinction has been made here between positive and negative angles. In other words, mines having an underwater course azimuth angle to the left of the course of the aircraft have been counted with those to the right. This procedure is probably justified, as left-right asymmetry is not pronounced. On the other hand, as may be seen from this presentation as well as from Figure 2, the forward trend of the mine results in considerable asymmetry along the course of the aircraft. In fact, twice as many recoveries are forward of the splash point as are behind it.

Comments

16. It should perhaps be noted at this point that the number of drops was too small for more complete analysis. Only eleven useful drops were obtained with parachutes and sixteen from high altitudes, rendering it difficult to determine dispersion characteristics. Moreover, other drop conditions were varied in each case.

17. As mentioned before, skipping of the mine may take place, involving two or even three separate splashes. This phenomenon explains, at least in part, why a number of the plots seem to represent an excessive amount of forward motion, and a number of others give visual sight points a considerable distance to one side or the other of the recovery point. If all the observers chose the original point of impact of the mine, the apparent forward motion could be due to a skip alone, or to a long, surf-board-like "slide" along the surface. If, on the other hand the observers did not choose the same splash for their sights, an apparent left or right motion of the mine may result, due to crossing of the lines of sight of the different observers. Comparison of our data with the corresponding drop photographs has proven valuable in confirming the effect of secondary splashes on the observers. Although some attempt was made by the observers themselves to select the final splash point, they were not always successful, as radar comparisons demonstrate.

18. Inasmuch as the depth data available[6] are quite accurate for the time of recovery, and could be corrected to the time of drop with available tide figures, the temptation to try to correlate depth with underwater range or azimuth might appear attractive. Such an attempt, however, is likely to lead to a completely spurious result. For example, if the target were situated above the deepest point in an area with a saucer-shaped bottom, and the mines

were all dropped near the target, an excellent correlation would result, indicating that the dispersion distance increased with a decrease in depth. The actual dispersion in this case, however, could be due entirely to other causes, and the correlation result merely from the depth of the bottom at a certain distance from the target. Thus the only meaningful variation will correspond to an average depth near the target, and this will differ for different target areas. Separate plots are shown for two average depths (see Figures 3a and 3b).

19. The results of this study seem to be in agreement, at least in form, with the results described by Beringer and Carver, reference 5. Our distribution appears consistent with their "over-simplified model taken from the dispersion of rifle bullets on a target," though the number of drops available to us did not seem to justify a complete statistical treatment. The percentage of mines outside a given radius from our data seems somewhat larger than that which they found. For instance, for water depths comparable with ours, their results showed about 93% in a circle of 60 foot radius (about 18.3 meters). Our 93% mark is at 68 meters. The discrepancy is probably due in part to less accurate observation and in part to the non-operational nature of the drops in our case.

REFERENCES

1. Geographic coordinates of the observation points: HPP Technical Report No. 4, (HPP:100:Ser 00370 dtd 14 March 52) Table III, page 24.

2. A report on the method devised will be forthcoming later.

3. d'Ocagne, Journ. de l'Ecole Pol. cah. 63 (1893), p. 1

4. Whittaker and Robinson, The Calculus of Observations, Fourth Edition, D. Van Nostrand, New York, 1944, p. 245

5. Beringer and Carver, Study of Underwater Dispersion of Aircraft-laid Ground Mines, HPP Technical Report No. 1, (HPP:510:Ser 06), dtd 15 June 1951

6. Whaley and Hipps, Inshore Survey Program, Interim Report VIII, Reference No. 52-5, Chesapeake Bay Institute, The Johns Hopkins University

TABLE I

Drop No.	Splash Coordinates x	Splash Coordinates y	Underwater: Range Meters	Underwater: Azimuth Degrees	Probable error, meters	Type of Mine	Altitude, feet	Water Depth, feet	Nominal Drop Area	Special Features of Drop
Dec. 13										
1.	+749.5	722	20.0	185	21.0	36	low	38	I	
2.	740	690	0	0	9.68	36	low	41	I	
3.	758.7	676.4	N.R.	-	3.74	36	low	-	I	
4.	725.4	676.2	17	13	14.53	36	low	41	I	
5.	752.1	603.6	N.R.	-	0.00	36	low	-	I	
6.	759.6	578.6	8.9	207	1.36	36	low	41	I	
Dec. 14										
7.	290	726	74	310	29.9	36	low	40	I	
8.	198	916	44	257	12.1	36	low	42	I	
9.	201	868.2	67.4	37	0.75	36	low	44	I	
10.	909.9	1384.2	10.9	63	0.35	36	low	35	D	
11.	894.4	1368.8	9.8	350	2.47	36	low	35	D	
12.	949.8	1417.4	7.	76	1.52	36	low	30	D	
Dec. 28										
13.	176	1012.4	19.1	221	1.48	39	2000	46	I	
14.	205.5	1066.8	15.5	36	3.23	39	3000	47	I	
15.	54.2	1080.6	5.0	47.5	0.00	36	low	47	I	
Jan. 9										
16.	-959.5	1792.2	31.5	13	0.91	36	2000	60	II	
17.	-380	1737.5	540	204	0.43	39	2000	60	II	
18.	-568.5	1873.0	81	274	4.37	36	low	63	II	C
19.	-566	1904.8	7.2	338	1.45	36	low	61	II	C
20.	-423	1691.4	7.0	121	0.77	36	low	56	II	C
21.	-432.1	1837.3	32.5	223	2.05	39	3000	60	II	
22.	-382.8	1689.8	8.4	321	1.69	39	3000	56	II	

Drop No.	Splash Coordinates x	Splash Coordinates y	Underwater: Range Meters	Underwater: Azimuth Degrees	Probable error, meters	Type of Mine	Altitude, feet	Water Depth, feet	Nominal Drop Area	Special Features of Drop
Jan. 11										
23.	-460	1690.4	N.R.	-	1.42	39	3200	55	II	
24.	-283.2	1539.2	51	6	4.90	39	3100	53	II	
Jan 15.										
25.	985.2	48.2	4.2	18	3.57	39	1700	43	I	
26.	1086.8	71.4	9.3	51	1.03	39	2000	42	I	
27.	838	88.4	N.R.	-	2.27	36	low	-	I	CF
28.	1117.5	69.2	3.1	100	0.00	39	2100	42	I	
29.	1197.7	88.6	10.3	154	0.11	39	1500	41	I	
30.	919.5	181.6	N.R.	-	2.43	36	low	-	I	C
31.	992.8	166.3	17.8	202	0.32	39	2800	47	I	
Jan. 17										
32.	-528.4	1882.4	17.4	328	0.30	39	2000	56	II	
33.	-574.8	1916.8	N.R.	-	1.67	39	1600	-	II	
34.	-269.7	1739.8	12.3	308	0.09	39	3000	42	II	
35.	-278.4	1727.1	3.7	220	0.88	39	3000	53	II	
Jan. 30										
36.	-536.8	1957.8	12.4	103	0.84	36	low	55	II	C
37.	-812.4	2196	408	243	1.39	36	low	47	II	CF
38.	-315	1749.75	21.8	164	12.9	39	3000	56	II	
39.	-546.4	1530	720	270	-	36	low	63	II	C
40.	-559.5	1957.7	4.6	245	0.55	36	low	60	II	CF
41.	-442.6	1944	7.3	34	0.87	39	3000	47	II	
42.	-457.4	1851.2	7.0	3	1.58	39	2800	60	II	
Feb. 5										
43.	-1019.9	2217.4	4.2	301	1.86	39	low	60	II	
44.	-194.25	1290.5	85.8	349	0.47	36	low	48	II	C

Drop No.	Splash Coordinates x	Splash Coordinates y	Underwater: Range Meters	Underwater: Azimuth Degrees	Probable error, meters	Type of Mine	Altitude, feet	Water Depth, feet	Nominal Drop Area	Special Features of Drop
Feb. 6										
45.	-589	1863	444	233	0.59	39	low	63	II	SK
46.	-377.6	1608.1	68.1	72	0.11	39	low	55	II	SK
47.	-434.9	1684.9	21.2	324	4.55	39	low	55	II	
48.	-525	1805.1	64	358	0.00	39	low	60	II	SK
49.	-474.5	1704	19.62	42	11.59	39	low	57	II	
50.	-402.2	1671.5	11.3	255	0.59	36	low	57	II	C
51.	-480.3	1742.4	N.R.	-	2.99	36	low	-	II	CF, SK 2
52.	-334.4	1598.4	30.6	11	5.38	39	low	55	II	SL
Feb. 8										
53.	-347.1	1691	7.7	60	5.53	39	low	56	II	SL
54.	-314.33	1665.3	32	10	17.25	39	low	57	II	SL
55.	-285.5	1621.6	N.R.	-	2.15	39	low	-	II	SL
56.	-282.3	1562.3	55	8	67.3	39	low	54	II	SL
57.	-145.5	1449.9	15.7	331	-	36	low	50	II	C
58.	-222.7	1563.1	31.6	112	-	25	low	56	II	C
59.	-208.2	1502.2	14.7	50	0.79	25	low	51	II	C
60.	-36.25	1307.9	19.5	226	3.56	36	low	49	II	C

SYMBOLS:
- N.R.: No Recovery
- Low: 200'-300'
- C: Parachute used
- CF: Parachute failed
- SK: Mine skipped on impact
- SL: Long slide along surface
- SK 2: Mine skipped twice

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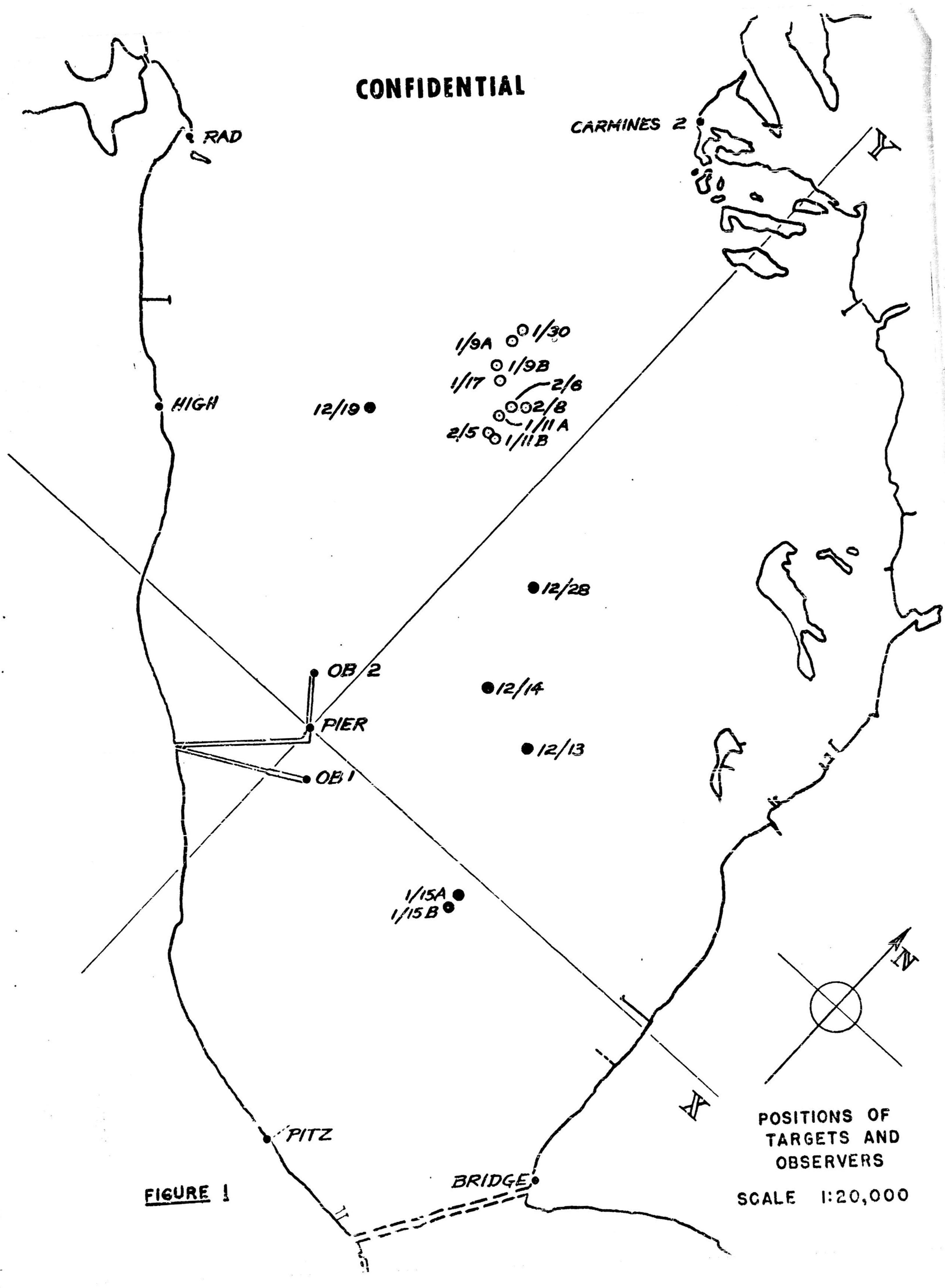
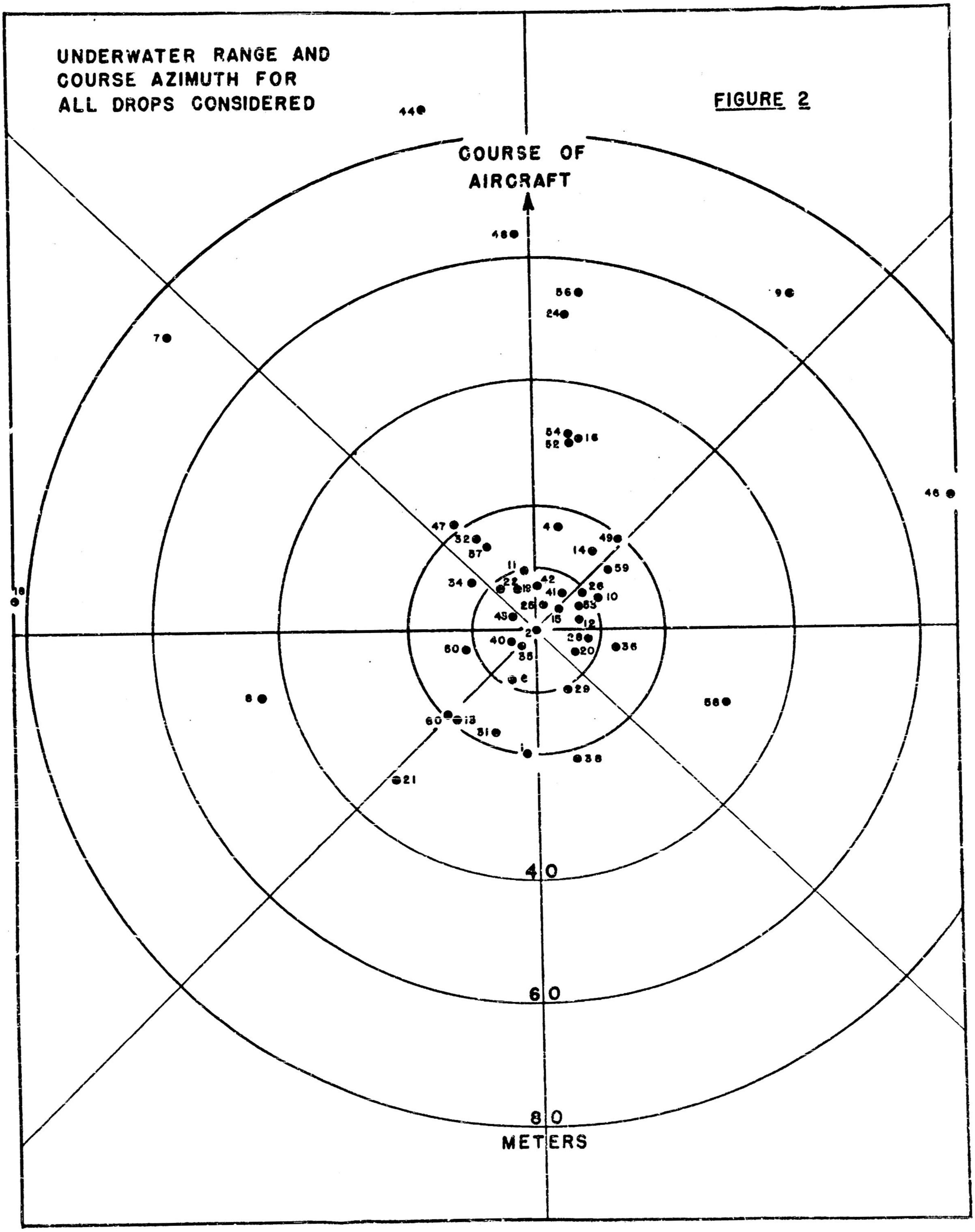
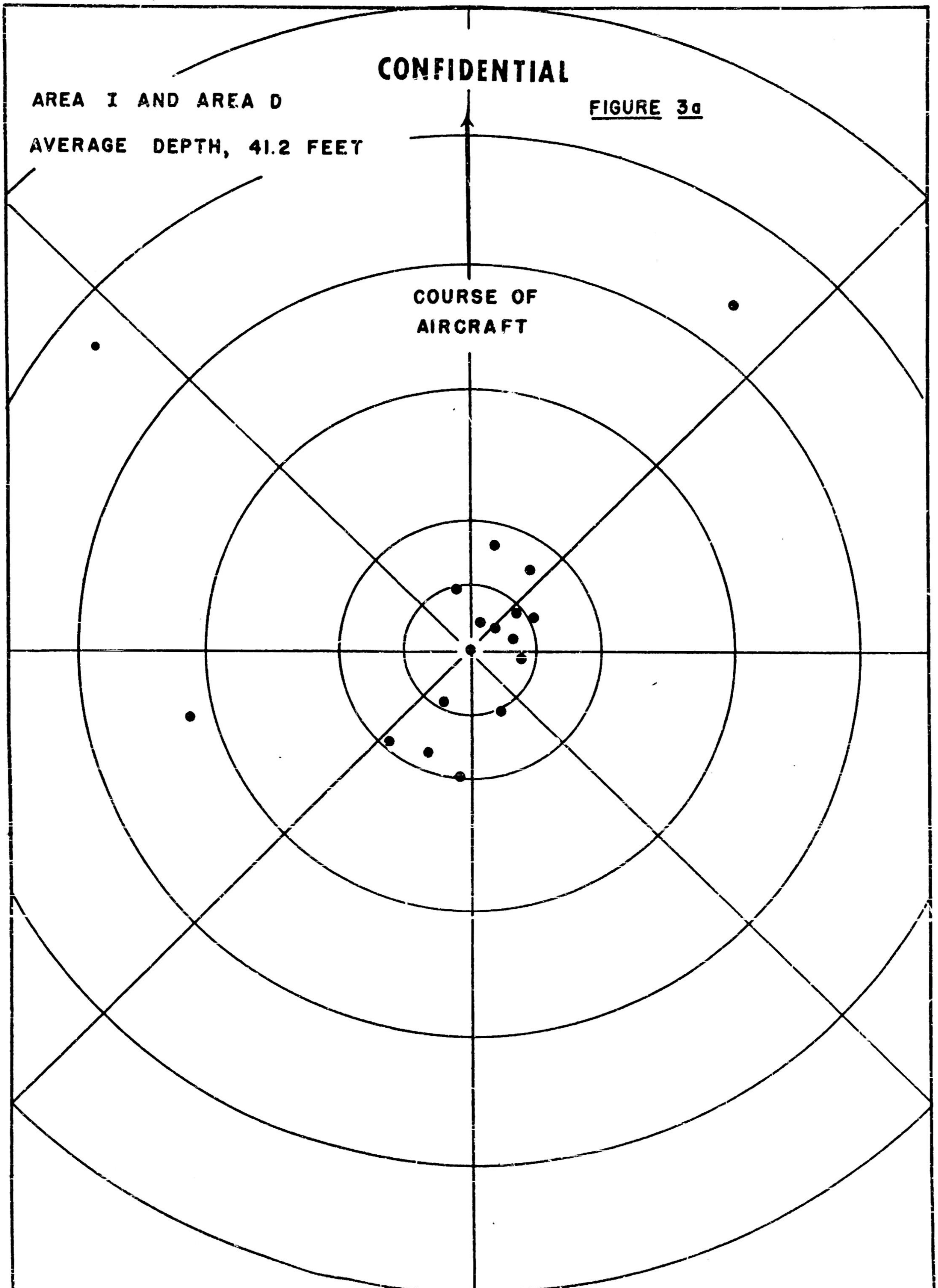


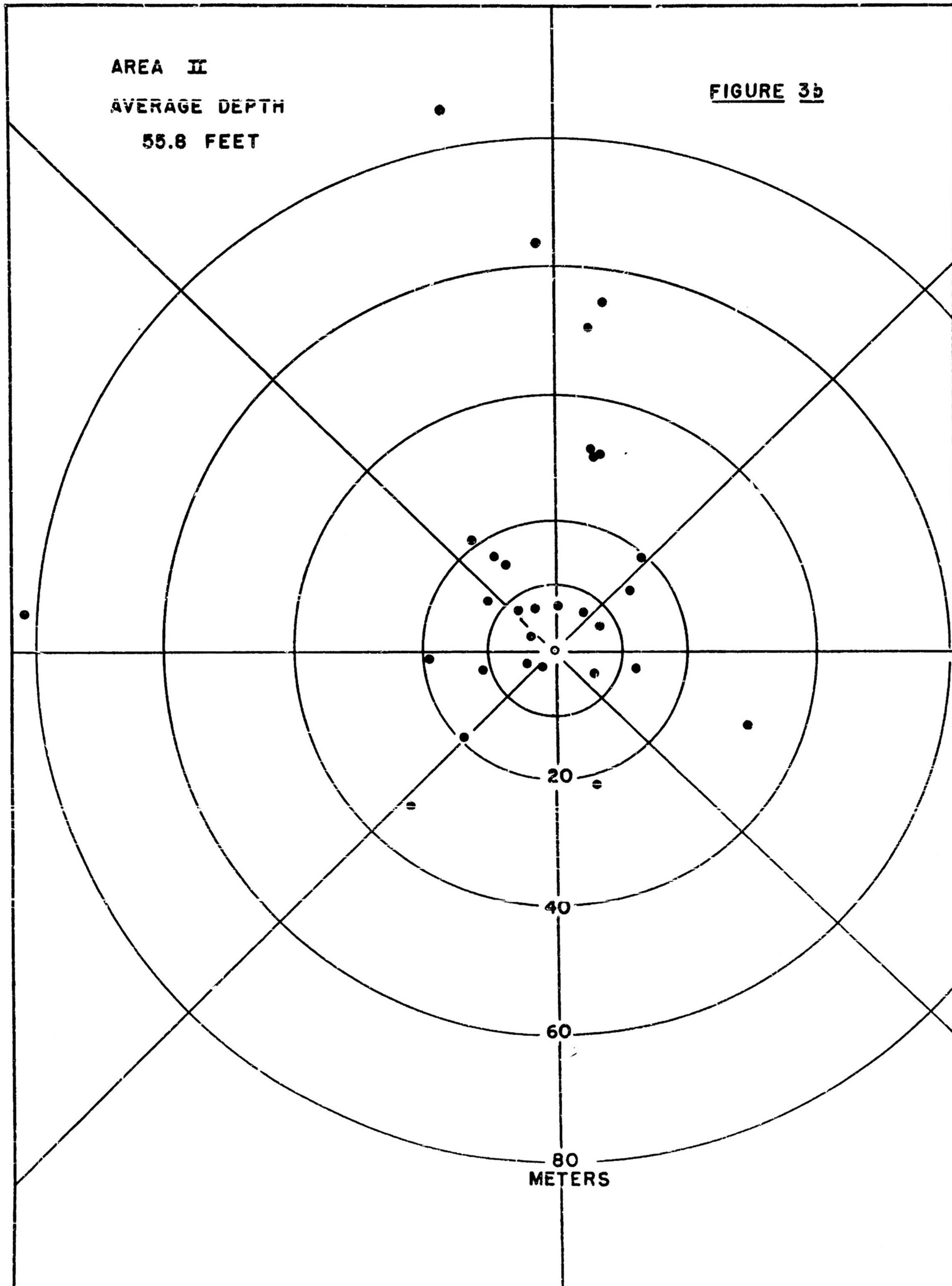
FIGURE 1

POSITIONS OF TARGETS AND OBSERVERS

SCALE 1:20,000

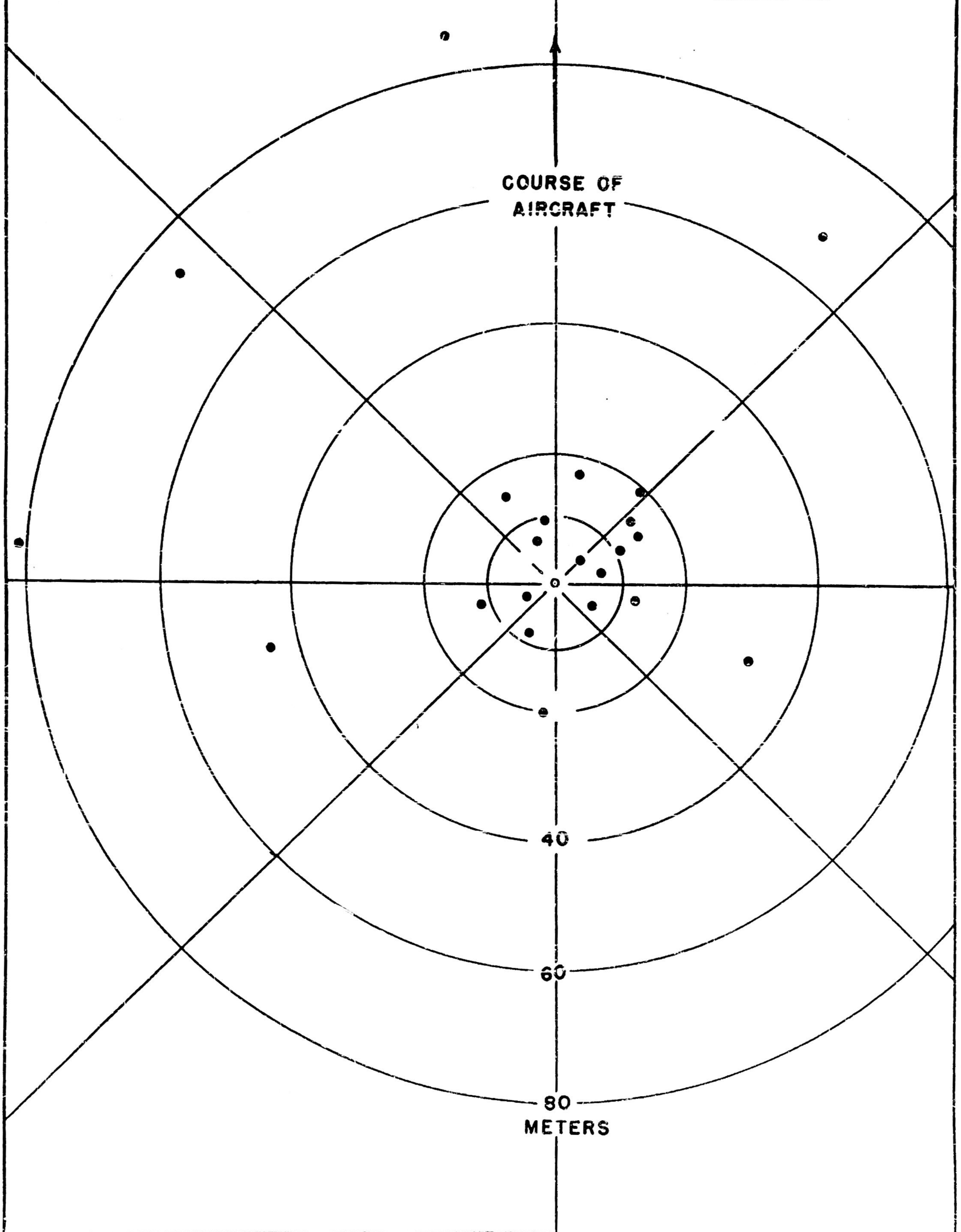

UNDERWATER RANGE AND COURSE AZIMUTH FOR ALL DROPS CONSIDERED
FIGURE 2
COURSE OF AIRCRAFT
40
60
80
METERS


AREA I AND AREA D
AVERAGE DEPTH, 41.2 FEET
FIGURE 3a
COURSE OF
AIRCRAFT


AREA II
AVERAGE DEPTH
55.8 FEET
FIGURE 3b
20
40
60
80
METERS

DROPS WITH PARACHUTES

FIGURE 4a



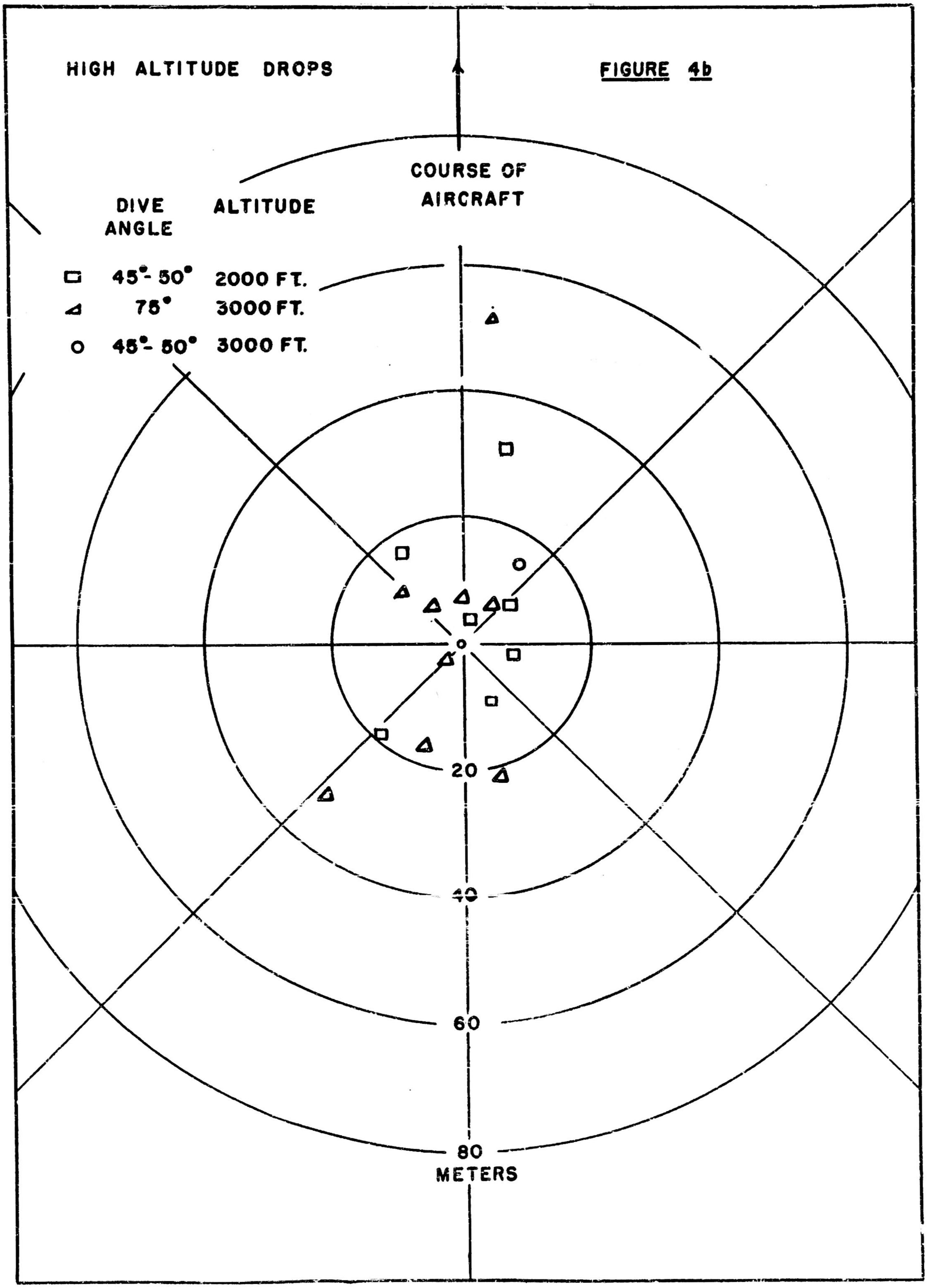

HIGH ALTITUDE DROPS
FIGURE 4b
COURSE OF AIRCRAFT
DIVE ANGLE
ALTITUDE
45°-50° 2000 FT.
75° 3000 FT.
45°-50° 3000 FT.
20
40
60
80
METERS

FIGURE 5a

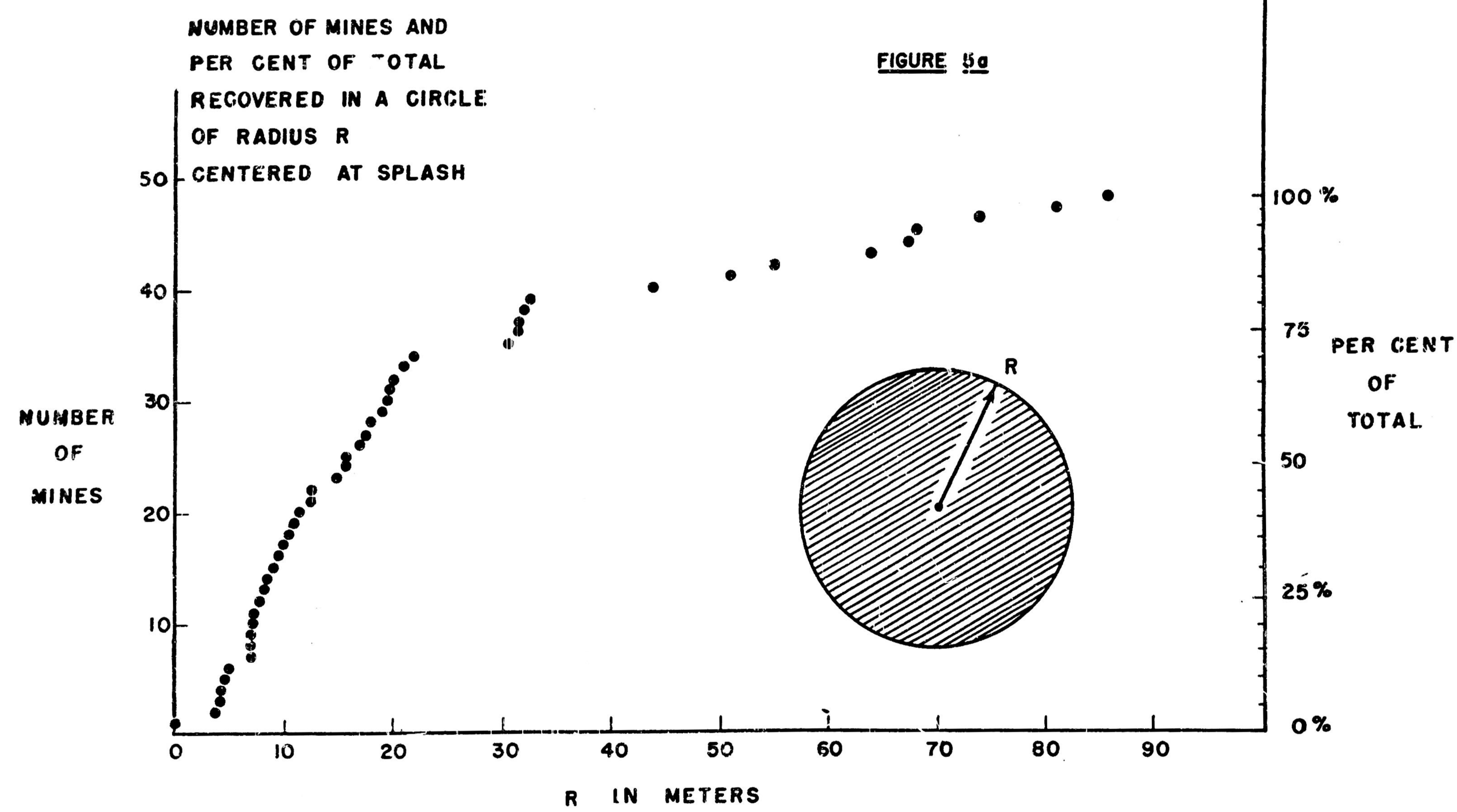

NUMBER OF MINES AND
PER CENT OF TOTAL
RECOVERED IN A CIRCLE
OF RADIUS R
CENTERED AT SPLASH
NUMBER
OF
MINES
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
R IN METERS
100 %
75
50
25 %
0 %
PER CENT
OF
TOTAL
R

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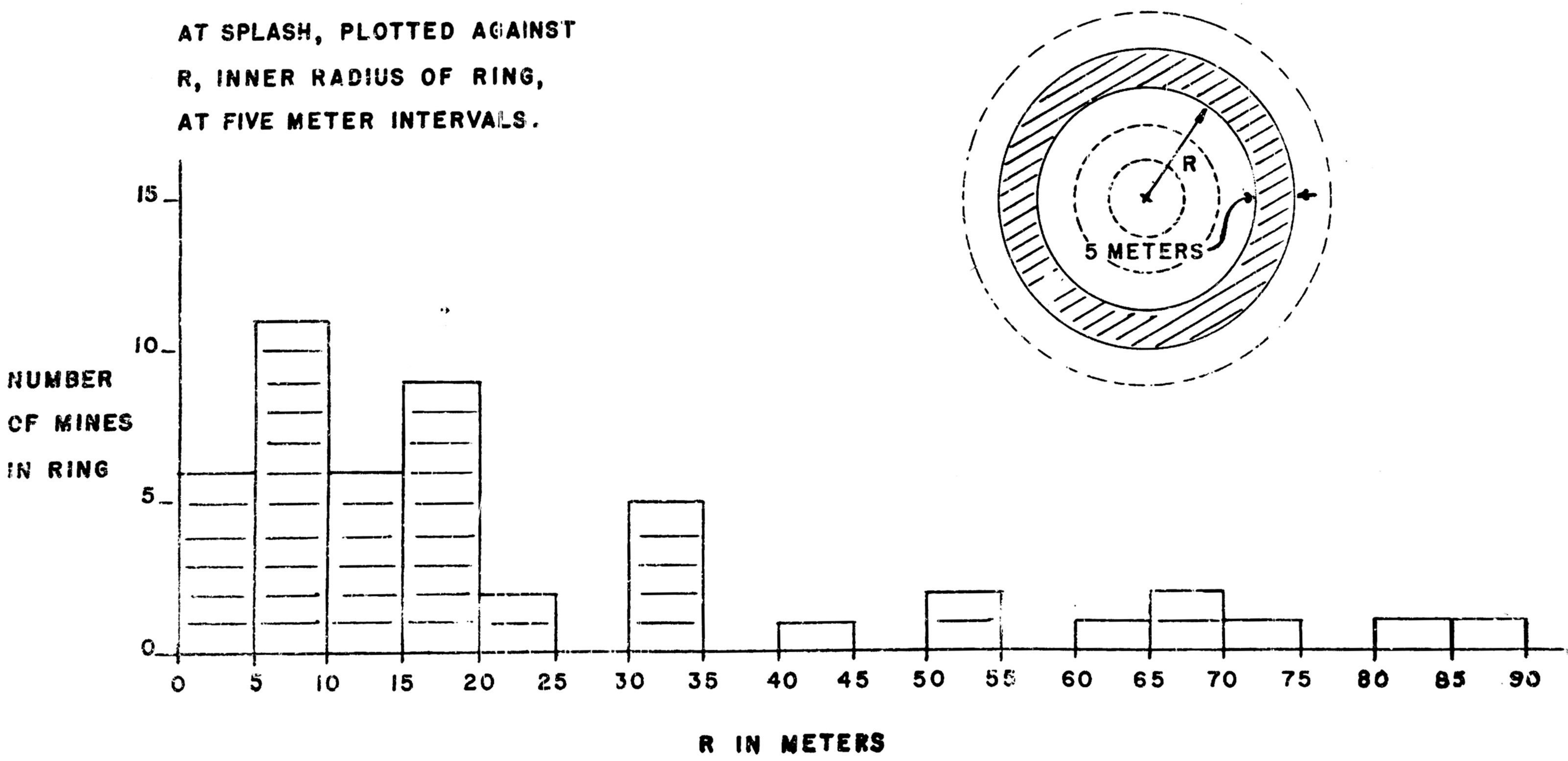
FIGURE 5b

NUMBER OF MINES IN A RING FIVE METERS WIDE CENTERED AT SPLASH, PLOTTED AGAINST R, INNER RADIUS OF RING, AT FIVE METER INTERVALS.



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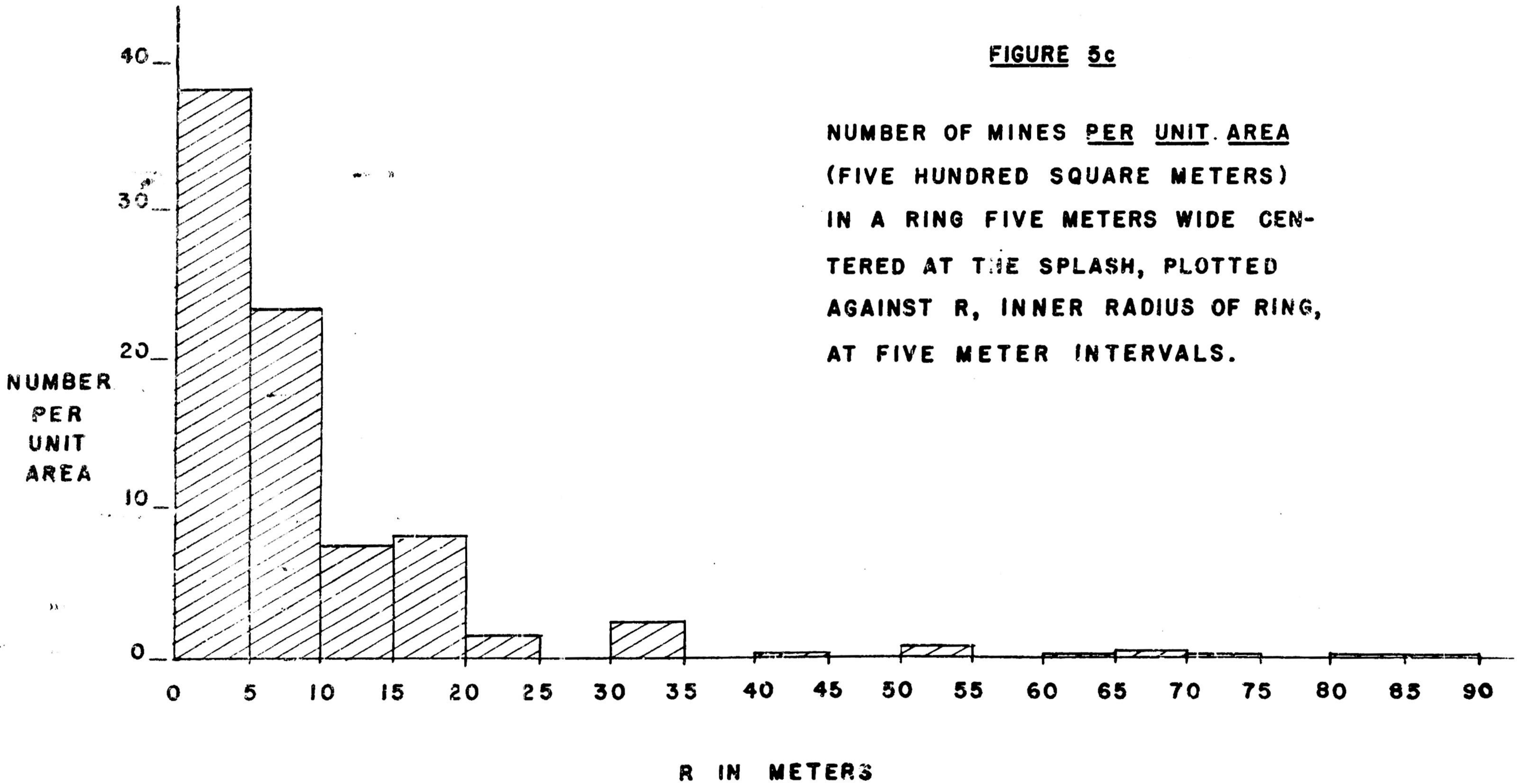

FIGURE 5c

NUMBER OF MINES PER UNIT AREA (FIVE HUNDRED SQUARE METERS) IN A RING FIVE METERS WIDE CENTERED AT THE SPLASH, PLOTTED AGAINST R, INNER RADIUS OF RING, AT FIVE METER INTERVALS.

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FIGURE 6

NUMBER OF MINES IN A 30° SECTOR PLOTTED AGAINST ANGLE OF CENTER-LINE (LEFT OR RIGHT) WITH COURSE OF AIRCRAFT.